even for panoramas, but also furnished many valuable hints with regard to light and shade, reflection and *chiaroscuro*, and the general means of reproducing as closely as possible on a level surface the raised appearance of solid forms. A competent judge of both arts might find it an interesting task to ascertain what share photography has had in the origin of the modern schools of painting, and in the manner of impressionists and pleinairists. It further taught landscape-painters to depict rocks and vegetation with geological and botanical accuracy, and to represent glaciers, which hitherto had been but rarely and never successfully attempted. It caught and fixed the changing aspect of the clouds, though only yielding a somewhat restricted survey of the heavens. It aided portrait-painters without exciting their jealousy; for, unable to rival them in representing the average aspect of persons, it only seized single, often strained and weary expressions, rendering almost proverbial the comparison between a bad portrait and a photographed face; nevertheless it supplied them on many occasions with an invaluable groundwork, lacking nothing but the animating touch of an artist's hand.

However, the recent progress of photographic portraiture claims the attention of artists in more than one respect. Duchenne and Darwin called into existence a new doctrine of the expression of the emotions; the former by galvanizing the muscles of the face, in order to imitate different expressions, the latter by inquiring into their phylogenetic development in the animal series. Both presented artists with photographs which quickly consigned to oblivion the copies hitherto employed for purposes of study in schools of art, dating chiefly from Lebrun; even the sketches in Signor Mantegazza's new work on "Physiognomy and Mimics" will scarcely enter into competition. On Mr. Herbert Spencer's suggestion, Mr. Francis Galton subsequently solved by the aid of photography a problem, which was previously quite as inaccessible to painters as the representation of an average expression to photographers. He combined the average features of the face and skull of a sufficient number of persons of the same age, sex, profession, culture, or disposition to disease or vice, in one typical portrait, which exhibits only those characteristic forms common to their various dispositions. This was effected by blending on one negative the faint images of a series of persons belonging to the same description. In the same manner, Prof. Bowditch, of Harvard Medical School, Boston, obtained the representative face or type of American students of both sexes, and of tramway conductors and drivers. In the latter instance, the intellectual superiority of the conductors over the drivers is plainly visible. How Lavater and Gall would have relished this!

Of course the average expression of a single person might be procured by similar means, if it were worth while summing up on the same plate repeated photographs of different expressions. Instantaneous photography, however, furnishes a welcome substitute for the average expression, by seizing with lightning swiftness the changing phases of the human countenance in their full vivacity. Here, again, pathology places itself at the disposal of art. M. Charcot has found that photographs of the convulsions and facial distortions of hysterical patients resemble our classical representations of the possessed. Raphael's realism in this respect is perhaps the most curious of all, being so much at variance with his idealistic nature. In the possessed boy of the "Transfiguration," a cerebral disease can be almost safely inferred from the Magendie position of the eyes; and the circumstance, recently observed in New York, that the left hand is depicted in a spasm of athetosis, would accord well with this diagnosis.[1]

(*To be continued.*)

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[1] Sachs and Petersen, "A Study of Cerebral Palsies," &c., *Journal of Nervous and Mental Diseases*, New York, May 1890.

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## TELESCOPIC OBJECTIVES.[1]

IT is a frequent source of disappointment to observers, especially beginners, to find that their instruments fail to answer to the tests which are so commonly found in astronomical text-books. It may be that the instrument in question is really an imperfect one; but if it be the work of a maker of repute, it is more probable the fault lies in the absence of proper adjustment, more especially if, for some reason or other, no responsible person is able to superintend the final fixing in position. The information hitherto published on the subject of adjustment, and the phenomena which accompany the various defects of an objective, is very scanty; and observers of all classes will therefore welcome the appearance of the little book recently issued by Messrs. T. Cooke and Sons, the well-known firm of telescope makers The book is the best testimony that one could wish for as to their thorough knowledge of their business, and it abundantly demonstrates that they are worthy of the confidence which astronomers have long placed in them. The benefit of their wide experience is now available to all, and observers need no longer remain in doubt as to the quality of their objectives, or of the course to be pursued in tracing the defects to their proper sources.

For full particulars of the methods to be adopted we must refer our readers to the book itself, but many of the points touched upon are of great interest, considered simply as optical phenomena, and a brief reference to some of them may not be out of place.

It is a matter of common knowledge that, owing to the undulatory nature of rays of light, the image of a luminous point, such as a star, must always be a small disk, the diameter of which varies in inverse proportion to the aperture of the objective. This "spurious disk" is surrounded by a series of diffraction rings, which gradually diminish in intensity away from the centre.

The calculations of Sir George Airy[2] show that the angular radii of the rings, in circular measure, are given by the formula $\frac{\lambda n}{2\pi e}$, where $\lambda$ is the wave-length of the light-rays in question, $e$ the radius of the objective, and $n$ a constant which depends on the distance from the centre. The first dark ring occurs when $n = 3{\cdot}83$, the second when $n = 7{\cdot}14$, and the third when $n = 10{\cdot}17$. Hence, the angular radius of the first dark ring, which is really the boundary of the spurious disk, may be easily derived from the formula $\frac{3{\cdot}83 \times \lambda}{2\pi e}$, or $\frac{1{\cdot}22\lambda}{2e}$.

The rings are brightest when $n = 5{\cdot}12$, $8{\cdot}43$, and $11{\cdot}63$, with intensities respectively about 1/57, 1/240, and 1/620 of that at the centre.

If $s$ be the angular radius in seconds of arc, as viewed from the centre of the objective, the formula becomes

$$n = \frac{2\pi e s}{\lambda} \,.\, \sin 1'' ;$$

and if $\lambda$ for mean rays be taken as ·000022 inch,

$$n = 1{\cdot}3846 \times e\,s.$$

For the first dark ring, therefore,

$$s = \frac{3{\cdot}83}{1{\cdot}3846e} = \frac{2{\cdot}76}{e}.$$

Messrs. Cooke put these expressions in the form—

$$\text{Angular diameter of first dark ring in circular measure} = \frac{2 \times 1{\cdot}22\lambda}{A},$$

$$\text{Linear diameter of first dark ring} = \frac{2F \times 1{\cdot}22\lambda}{A};$$

where A = aperture, and F = focal length.

For a square aperture the conditions are different, and the size of the first dark *square* is given by the formula $\frac{2\lambda F}{A}$.

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[1] "On the Adjustment and Testing of Telescopic Objectives." (T. Cooke and Sons, Buckingham Works, York.)

[2] "Undulatory Theory of Optics," 1877 edition, p. 80.

Some interesting facts given by Messrs. Cooke show the remarkable agreement between the theoretical and observed values of these diameters. "A 6-inch objective, of 91 inches focal length, was directed to a bright star, and the objective cut down, in the first place, to a *square* aperture, 1·5 inches diameter. The mean of four measurements gave the diameter of the first dark ring (in this case square in shape) as ·0027 inch, while the formula $\frac{2F\lambda}{A}$ (where $\lambda = 1/45600$ inch) gives ·00266 as the theoretical value. A circular aperture, diameter 1·22 inches, was then placed in front of the objective, when the mean of four measurements gave a diameter of ·0039 for the first dark ring, while the formula $\frac{2F \times 1{\cdot}22\lambda}{A}$ gives a value of ·0040" (p. 31). "The diameter of the first dark ring, as depicted with the whole aperture of 6 inches in use, was also measured as nearly as its minute size would allow, the measurement obtained ranging about ·0008 (subject to an error of perhaps 10 per cent.), while the value given by the formula $\frac{2F \times 1{\cdot}22\lambda}{A}$ is ·00081" (p. 32).

As the spurious disk fades away into the first dark ring, its apparent diameter will depend on the intrinsic brightness of the star observed, and also to some extent on irradiation. Hence the necessity for measuring the rings, and not the "disks" themselves.

An important fact follows from the application of these considerations, for on the apparent diameter of the spurious disk depends the dividing power of the objective. If the diameter of the star disk—which may, on the average, be taken as half that of the first dark ring—be greater than the distance between the components of a double star, the telescope must obviously fail to divide it, no matter what may be the power of the eye-piece employed. "In all objectives having their focal lengths equal to fifteen times the aperture, the linear diameter of the spurious disk may be said to average ·0004 inch, or about 1/2500 inch. With 6 inches aperture this corresponds to an angular diameter of 0·9 second, and in a 12-inch aperture to 0·45 second. So these respectively represent the dividing powers of such apertures upon double stars of average brightness" (p. 31). For similar apertures, the values given by Dawes for stars in which both components are of the sixth magnitude are 0″·76 and 0″·38 respectively. To reduce the star disks to the extent necessary for the separation of the components of the spectroscopic binary $\beta$ Aurigæ (the angular distance being about 0″·005), an object-glass no less than 80 feet in diameter would be required.

The images of a star with the diffraction rings as yielded by a sensibly perfect objective are shown in Fig. 1.[1] Fig. 1, *a*, represents the focused disk and ring system seen under a high magnifying power; 1, *b*, and 1, *c*, are sections of the cone of rays taken very near to and on opposite sides of the focus, also seen with a high power; and 1, *d*, is a section taken about $\frac{1}{4}$ of an inch on either side of the focus, and viewed with a moderate power.

Before this perfection of image can be realized, we gather that the objective must satisfy the following conditions:—(1) The optic axes of the flint and crown glass lenses should be coincident. (2) This common axis should pass through the centre of the eye-piece. (3) The dispersions of the flint and crown should neutralize each other for the most visible rays of the spectrum. (4) There should be no spherical or zonal aberration. (5) The lenses should be free from astigmatism.

The second of these adjustments is practically the only one over which the observer himself has any control, and he must remain contented with the means of ascertaining how far his objective satisfies the remaining conditions enumerated.

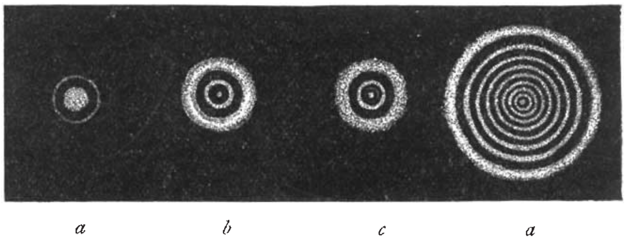

FIG. 1.—Diagrams showing spurious disk and diffraction rings seen with a perfect objective.

The process of testing an objective is considerably complicated by the imperfections of the eye as an optical instrument. Its want of achromatism when the full aperture of the pupil is used may frequently lead the observer astray in making observations in which colour effects are to be noticed. This defect is demonstrated, as pointed out on p. 14, by the fact that coloured fringes are observed to surround the image of a star seen in the open field of a reflector, of the perfect achromatism of which there can be no question. A sound practical hint accompanies this statement. The use of a power from 50 to 70 times the aperture in inches is recommended for purposes of testing, in order that the pencil of rays entering the pupil may be reduced; for if the power be equal to or less than the quotient of the diameter of the objective and the diameter of the pupil, the full aperture of the pupil is utilized, and the defect is consequently at its maximum.

Colour-blindness, of which no mention is made by Messrs. Cooke, is also common, and it is obvious that no colour-blind eye is competent to make tests depending on colour phenomena.

Astigmatism, too, is not an uncommon defect, the rays falling along one diameter of the lenses of the eye being refracted in a greater or less degree than those falling along the direction at right angles. Oculists combat this by supplying compensating astigmatic lenses as spectacles; and unless such compensation be perfect, an astigmatic eye must clearly be disqualified from making some of the test observations.

Another complication arises on account of atmospheric dispersion (p. 18). This, of course, is at its maximum for stars on the horizon, and the image of such a star would appear to have a red fringe on the upper and a green or blue fringe on the lower side, even in the most perfect telescope, unless a compensating eye-piece be used. Hence the importance of selecting stars of considerable altitude for purposes of adjustment and testing.

Further, the Huyghenian and Ramsden eye-pieces, which are almost universally used, are not achromatic in the strict sense of the term, and the eye-piece used for testing should therefore not be selected at random (p. 13).

Bearing these facts in mind, one may proceed to test the adjustments referred to.

(1) Any difference in the position of the axes of the component parts of the objective will cause the combination to act somewhat in the manner of an object-glass prism, such as is used in photographing stellar spectra, and the image of a star seen under such maladjustment will appear as a spectrum. The red end of the spectrum will obviously lie on the side towards which the flint is displaced with regard to the crown lens, an effect which is most noticeable when the eye-piece is racked within the focus (p. 17).

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[1] The diagrams are reproduced with the permission of Messrs. Cooke.

(2) This adjustment is technically called "squaring on," and is usually provided for in telescopes over 3 inches in aperture. If the optic axis of the objective does not pass through the centre of the eye-piece, the diffraction rings which are seen when the star is out of focus, will appear oval, and the focused image will be fan-shaped (p. 8). This follows from the fact that we are dealing with an oblique section of the cones of rays from the object-glass, and the rings will be most expanded and dimmest on the side which is furthest from the object-glass.

Fig. 2, *a*, represents the rings seen when the star is out of focus in the case of an objective seriously out of square, and Fig. 2, *b*, the corresponding focused image.

(3) Ordinary objectives should be so corrected that all the rays between C and F of the spectrum are brought to a common focus, these being the rays to which the retina is most sensitive. When this is done the objective is "over-corrected," and the rays less refrangible than C are brought to a shorter focus, while those more refrangible than F are focused at a greater distance outside. Hence, supposing a white star like Vega is observed, the focused image should be surrounded by an almost imperceptible blue fringe. A little way within the focus the image should show a reddish nucleus, and outside the focus a bluish centre should be observed. The effect of the colour of the star observed must be carefully guarded against (p. 16), and an eye-piece of sufficient power should be employed, for the reason already stated.

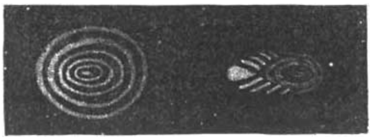
*a* *b*

Fig. 2.—Appearances observed when the objective is out of square.

A good method of testing for achromatism is to focus the image of a star on the slit of a spectroscope. If the image be perfectly achromatic, as in the case of a reflector, the spectrum seen will be a line of uniform thickness. Any departure from this will be indicated by local widenings of the spectrum. With an ordinary objective, the spectrum should be a narrow line from C to F, widening out at each end.

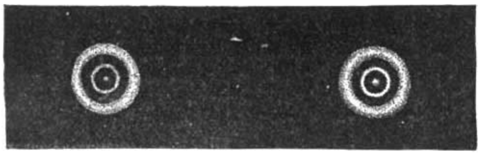
*a* *b*

Fig. 3.—Appearances due to spherical aberration.

(4) The absence of proper correction for spherical aberration produces very interesting features in the diffraction rings, some of which are admirably shown by the diagrams which are reproduced in Figs. 3, *a*, and 3, *b*. These represent sections of the cone of rays within and outside the focus respectively in the case of a lens in which there is *positive* aberration—that is, in which the rays from the outer parts of the object-glass come to a shorter focus than the central rays. In the first figure the concentration of light in the outer ring is the chief characteristic, while in the second the central ring is relatively brighter.

Zonal aberration, in which different parts of the objective have slightly different foci, modify the ring systems in a very remarkable fashion. In this case, the rings will not gradually diminish in intensity, but will vary according to the degree of imperfection. Figs. 4, *a*, and 4, *b*, show a good example of this, being sections taken within and outside the focus respectively.

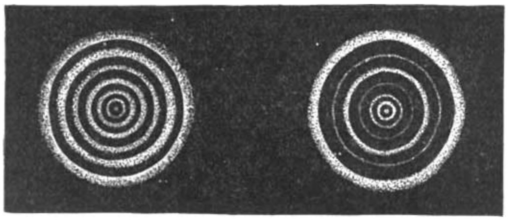
*a* *b*

Fig. 4.—Effects of zonal aberration.

(5) The effect of astigmatism in the objective will be to produce ellipticity in the rings, a very decided example of which is shown in Fig. 5.

Fig. 5, *a*, is a section taken within the focus, and Fig. 5, *b*, a section taken at the same distance outside. The combined effects of an astigmatic objective and an astigmatic eye may obviously be very variable.

*a* *b*

Fig. 5.—Elliptic rings produced by astigmatism.

Other causes may also operate in the modification of the diffraction rings, and some good examples are given The effects of the flexure of a lens supported on three points, for instance, are admirably shown in Fig. 6, *a*. Those who have seen photographs in which bright stars appear with their conventional rays will now have no difficulty in understanding their origin. They depend simply upon the distortion of the lens or mirror with which the photograph was taken, and the number of rays will correspond to the number of points of support.

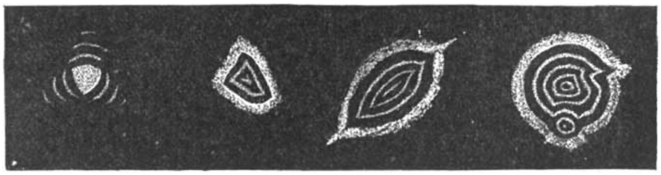
*a* *b* *c* *d*

Fig. 6.—Diagrams showing effects due to (*a*) flexure; (*b* and *c*) strain in cell; (*d*) veins in objective.

An objective which is strained in its cell, but properly squared on, may produce a distortion of the rings similar to that shown in Fig. 6, *b*. A more violent case of mechanical strain is shown in Fig. 6, *c*, and the presence of veins of unequal refractive power may affect the rings somewhat in the manner shown in Fig. 6, *d*.

A. Fowler.